In studying the effectiveness of iodine as a disinfectant for swimming pools, the authors found it to be more effective than chlorine. Furthermore, iodine had no unpleasant side effects.

EFFECTIVENESS OF IODINE FOR THE DISINFECTION OF SWIMMING POOL WATER

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CHLORINE added either in the form of a gas or as one of the commercially available high test hypochlorites is unquestionably the most widely used agent for the disinfection of swimming pool water. In recent years bromine has been suggested for this purpose and equipment for its continuous feeding is commercially available, but to date it has found relatively little acceptance.

Chlorine, however, as a disinfecting agent for swimming pool water has certain disadvantages. When applied to water it first reacts with ammonia, ammonium compounds, and other nitrogenous compounds which may be present to form chloramines. When added in a concentration sufficient to destroy these compounds the process is termed "breakpoint" chlorination and any chlorine remaining after these compounds have been destroyed is called "free" chlorine residual. Chlorine present in water in the form of chloramines is called "combined" chlorine and measured residuals are termed "combined chlorine residuals." Within the preferred pH range of swimming pool water, namely 7.2-7.8, monochloramine is the main compound present. Numerous investigators, notably Wattie and Butterfield[1] have shown that the ability of chloramines to destroy bacteria is far less than that of free available chlorine. These investigators demonstrated that in chlorine-free, chlorine demand-free water of pH 7.8 some Escherichia coli survived after 120 minutes' exposure to water containing 0.30 ppm of chloramine and at pH 8.5, some E. coli survived for 240 minutes at the same chloramine concentration, namely 0.30 ppm. In contrast, no E. coli survived after five minutes' exposure to water containing only 0.07 ppm of free chlorine at pH 7.8 and at pH 8.5 no E. coli survived after 10 minutes' contact with water containing 0.07 ppm of free chlorine. The statement is commonly made that free chlorine is approximately 30 times as effective as chloramines in bactericidal efficiency.

Also, when chlorine is added in an amount sufficient to destroy ammonia and other nitrogenous compounds present in the water, there is formed nitrogen trichloride which has a distinctive odor and may cause eye and nose irritation to some bathers.

It has been shown that the bactericidal activity of free chlorine is due almost entirely to hypochlorous acid formed by its reaction with water. Since at high pH values this acid is neutralized to form the hypochlorite ion, the bactericidal efficiency of chlorine decreases steadily as the pH of the water increases.

The following tabulation illustrates the effect of pH on the hypochlorous acid present in water:

Per cent of Free Available Chlorine as: [2]

pH	Molecular Chlorine	Hypochlorous Acid	Hypochlorite Ion
4	0.5	99.5	0
5	0	99.5	0.5
6	0	96.5	3.5
7	0	72.5	27.5
8	0	21.5	78.5
9	0	1.0	99.0
10	0	0.1	99.9

Finally, one may envision a situation where a free chlorine residual is present in the water at the beginning of the daily peak load of a swimming pool. As the ammonia content of the water increases, however, this free chlorine residual is quickly converted to a combined chlorine residual and the bactericidal property of the chlorine in the water is greatly decreased as has been shown.

In recent years attention has been directed toward the use of iodine as a disinfecting and sanitizing agent in a variety of fields, notably in water purification and in restaurant, dairy, and hospital sanitization. Several novel and effective iodine preparations, such as the "Iodophors" and other products which liberate elemental or "diatomic" iodine, are now on the market. The public is becoming accustomed to iodine's use in fields other than as an antiseptic. It is widely used in the form of iodized salt in human foods and animal feeds. Our Armed Services some years ago adopted "Iodine" tablets in place of Halazone (chlorine) tablets for disinfection in the field of water in canteens, based on the finding that iodine in drinkable dosages will kill amebic cysts while chlorine will not. And, finally, the price of iodine has come down to a level where the unique properties of iodine will permit it to compete more favorably with its cheaper and widely used halogen competitor, chlorine.

The very practical result of these developments is that iodine is acquiring a steadily increasing commercial importance in routine disinfection and sanitization procedures. More and more federal, state, and local agencies are approving the use of iodine preparations for various disinfecting and sanitizing purposes, notably in the fields of dairy, restaurant, and hospital sanitization previously referred to; and further growth in these directions at an accelerated rate would seem to be a reasonable expectation. Because of these developments it has been felt that a thorough study should be made of the efficiency of iodine as a disinfecting agent for swimming pool water and this investigation was planned with that objective in view.

Swimming Pools Used for Study

In planning the study two courses of action were open. The first was to select one or possibly two pools for detailed and intensive study of the various factors involved. The second was to select a larger number of pools varying in size and bathing load and to study them for an extended period of time under actual operating conditions. The latter plan was adopted. Seven pools in Gainesville, Fla., and one in Coral Gables, Fla., were selected for the study. The basic data describing the various pools are given in Table 1. They ranged in size from the Olympic size pool of the University of Florida to small home-type pools at three motels. Bathing loads varied from 1,727 persons who used the University of Florida pool on the first day of the study to as few as three persons per day using the small motel pools.

For each of the three large pools used in these studies hourly or daily bather counts were available. For the smaller pools bathing loads are based on informal records kept for us by swimming pool operators. It may also be mentioned that bathing loads were fairly

Table 1—Basic Data on Eight Pools Studied

Pool No.	Identification	Size	Depth Shallow End	Depth Deep End	Capacity Gal.	Number and Type of Filter	Type of Chlorinator	Other Chemical Feeders Soda-Ash	Other Chemical Feeders Alum	Recirculation GPM	Theoretical Turnovers
1	Manor Motel	28¼′ x 58½′	3′	8′ 6″	66,000	Diatomite (1)	Solution pump	No	No	185	4
2	Lincoln Pool	42′ x 75′	3′ 3″	10′	148,000	Diatomite (1)	Gas	Yes	No	400	4
3	Tom Sawyer Motel	20′ x 40′	3′	8′	33,000	Pressure Sand (4)	Solution pump	Yes	Yes	60	3
4	Bambi Motel	20′ x 40′	3′	8′	33,000	Diatomite (1)	Solution pump	No	No	90	4
5	Holiday Inn	30′ x 50′	3′ 4″	8′ 6″	68,000	Diatomite (1)	Solution pump	No	No	190	4
6	Golf Club*	35′ x 70′	3′	9′	98,600	Diatomite (2)	Gas	No	No	225	3†
7	University‡	60′ x 150′	4′	12′	500,000	Diatomite (3)	Gas	No	No	1,150	3
8	Riviera Courts Motel, Coral Gables	20′ x 43′	3′	8′	36,000	Diatomite	Solution pump	No	No	90	4

* Pool emptied weekly on Sunday nights, refilled Monday. Own well used as water source. Alkalinity 136 ppm.
† Pump capacity has dropped to 225 GPM permitting only three turnovers—theoretical 3.7.
‡ pH + soda-ash blocks used for pH control.

uniform throughout the day since the three large pools were used for instructing swimming classes in the mornings and were available for recreational use in the afternoons and early evenings.

Description of Field Procedures

As a control, the first three weeks of the study, July 7-25, were devoted to the collection of data representing normal swimming pool operation with chlorine gas being used at the three large pools and high test hypochlorite at the four small Gainesville pools. Values for residual chlorine and pH during this period were taken from pool operating records or determined at the time of the visits either by the pool attendant or the field chemist. At the Riviera Courts Motel in Coral Gables data covering the use of chlorine were collected for three days and for the use of iodine for the seven following days.

Methods for Addition of Iodine

For the three weeks' period beginning July 28 and ending August 15, 1958, all pools except one received potassium iodide equivalent to a dosage of one ppm of iodine on Tuesdays and Saturdays of each week. The University of Florida pool received the iodide dosage for only two weeks since that pool was closed for the summer on August 8.

The crystalline potassium iodide was broadcast by hand over the surface of the pool with a small amount of chlorine added to release free iodine. This operation was carried out in accordance with the Marks and Strandskov "Procedure for Disinfecting Aqueous Liquid" (U. S. Patent 2,443,429 assigned to Wallace and Tiernan Products, Inc.). On August 16, the dosage was doubled; potassium iodide equivalent to two ppm of iodine being applied to the four Gainesville motel pools twice weekly during the remainder of the test period.

At the Gainesville Golf Club pool treatment with potassium iodide using a minimum amount of chlorine to release free iodine was discontinued on August 20. Feeding of a partly saturated water solution of iodine was begun on August 21. This feed was continued through September 1.

At the Lincoln pool for the greater part of the tests with potassium iodide excessive amounts of chlorine beyond the amounts required for releasing the contained iodine were inadvertently fed. Such data were not representative. On August 20 at the Lincoln pool feeding of a 2 per cent solution of iodine in potassium iodide was begun and continued through September 1.

From time to time during the course of the tests a combination of potassium iodide and an iodine-releasing material was added to one or another of the pools. At the Riviera Courts Motel this was the only method of application used and all bacteriological data from that pool reflect results obtained in this manner.

Sampling

Methods of sampling are described in Appendix A.

Laboratory Methods of Analysis

Bacteriological tests were made as described in Appendix B.

Chemical tests for determination of residual chlorine and residual iodine are described in Appendix C.

Discussion of Data

During the study, chemical and bacteriological tests were made regularly. The number of chlorine and iodine samples tested and the number having a most probable number of 2.3 or less are shown in Table 2.

Efforts were made to determine the lowest concentration of iodine that would be effective. Accordingly, some very low iodine residuals were recorded.

Table 2—Relationship of Halogen Residual to M.P.N.—Eight Pools

Distribution of Values	No.	Cl_2 Per cent of Subtotal	No.	I_2 Per cent of Subtotal
Samples with no measurable residual	2	..	41	..
Samples with M.P.N. 2.3 or less	2	100.0	23	56.1
Halogen residual 0.01–0.09 ppm	0	..	36	..
Samples with M.P.N. 2.3 or less	..	..	26	72.2
Halogen residual 0.10–0.19 ppm	46	..	36	..
Samples with M.P.N. 2.3 or less	36	78.3	29	80.5
Halogen residual 0.20–0.29 ppm	67	..	31	..
Samples with M.P.N. 2.3 or less	60	89.4	27	87.1
Halogen residual 0.30–0.39 ppm	40	..	16	..
Samples with M.P.N. 2.3 or less	33	82.5	14	87.5
Halogen residual 0.40–0.49 ppm	35	..	5	..
Samples with M.P.N. 2.3 or less	33	94.3	5	100.0
Halogen residual 0.50 ppm or more	82	..	57	..
Samples with M.P.N. 2.3 or less	74	90.2	56	98.2
Halogen residual undertermined but +	24	..	48	..
Samples with M.P.N. 2.3 or less	23	95.8	47	97.7
Total samples, 8 pools	296		270	
Most probable number $\lesseqgtr$ 2.3	261		227	
Fraction of total samples	88.1%		84.1%	
Total samples with measured Halogen res.	270		181	
Most probable number $\lesseqgtr$ 2.3	236		157	
Fraction of subtotal as described	87.4%		86.7%	
Total samples Halogen res. > 0.20 ppm	224		109	
Most probable number $\lesseqgtr$ 2.3	200		102	
Fraction of subtotal as described	89.3%		93.6%	
Total samples Halogen res. > 0.10 ppm	270		145	
Most probable number $\lesseqgtr$ 2.3	236		131	
Fraction of subtotal as described	87.4%		90.3%	

Inspection of Table 2 shows that 28 per cent of the samples had iodine residuals below 0.10 ppm. Even at these low levels 63 per cent of the samples revealed water of acceptable quality.

In most of the tests using iodine it was fed in the form of potassium iodide at the rate of two to four parts per million of iodine per week. The iodine was released by feeding chlorine at levels low enough to leave a residual of iodide in addition to the free iodine made available. (One part of iodine is released from iodide by 0.28 part chlorine.)

Some of the free iodine which was reduced to iodide by combining with bacteria and other matter again was released by subsequent applications of chlorine, thus maintaining free iodine residuals.

In two pools it was not feasible to decrease the chlorine fed to the very small amount required to liberate iodine from the potassium iodide. Under these conditions it is assumed that the excess chlorine converted the iodine to the inactive iodate form.

In another pool, potassium iodide and an iodine-releasing agent were fed by hand to the surface of the pool. The average daily dosage of iodine was one part per million with an average residual of 0.28 ppm. This emphasizes that a small pool with a light bathing load does not differ greatly in total iodine consumption from a large pool with a very heavy bathing load. It also indicates that the iodine demand of a given pool is much less dependent upon the bathing load than is the case with chlorine.

On the basis of equal residuals of iodine and chlorine, the quality of the treated water is the same. As pointed out, however, free chlorine combines quickly with ammonia introduced by swimmers and may be immediately converted to the slow acting chloramine form. Another factor of importance is the amount of the element required to maintain a proper residual. For example, in one pool chlorine was fed at the rate of 7.7 parts per million per turnover or 15.6 ppm per pool day. This is at the rate of 109.2 ppm total chlorine per week. Chlorine residuals ranged from 0.2 to 0.8 ppm with pH between 7.1 and 7.9. In contrast, iodine fed at the rate of four ppm per week as potassium iodide (released by small amounts of chlorine) provided water of acceptable quality with residuals in the range of 0.11 to 0.40 ppm, with some higher values recorded.

Relative Effectiveness of Chlorine and Iodine as Algaecides

During the course of the work all pools were closely observed for the possible appearance of algae. During the entire investigation no algae were present in any pool in a concentration visible to the naked eye. This is believed to indicate that both chlorine and iodine acted as efficient algaecides during the course of the work. Two other items of evidence may be offered in support of that statement. The first is that at the Tom Sawyer Motel pool a small wading pool adjoined and was connected to the main pool. Growths of algae were visible in the wading pool during the course of the work and living cultures were removed for laboratory study, whereas none were present in the main pool. This probably resulted from poor recirculation and the very shallow water depth, approximately 18 inches. Second, within a week following shut down of the Lincoln pool, a prolific growth of algae developed before the pool was drained.

One of the authors of this paper is conducting a careful laboratory study of the relative effectiveness of chlorine and iodine as algaecides and his results will be published as a separate paper. Meanwhile, he has summarized his conclusions as follows:

> "The control of algae in swimming pools shows two aspects. (a) The immediate growth of algae, especially in abundance as evidenced by visible observation, is well controlled by the usual algaecides and by iodine, not usually thought of in this connection but apparently fully effective. (b) There is, however, a small group of algae which in treated pools either grow with extreme slowness or remain static. When samples from such pools are brought into the laboratory and maintained at suitable temperatures but not open, they evidently develop growths of blue-green algae, chlorococcales (green algae), and Xanthophyceae (yellow algae). Control, therefore, must be maintained for these can readily seed a pool if treatment fails."

Effect of Iodine on Color of Pool Water

When either pellets or crystals of a mixture of potassium iodide and an iodine-releasing compound were added by hand to swimming pools, there developed a dark brown cloud at those points where iodine was being released. When this was done with swimmers in the pool the cloud was quickly and uniformly disseminated throughout the water. When, however, iodine was added continuously through the pool circulating system no such brown cloud or visible color developed. The color of the water of pools containing appreciable iodine residuals was a clear, pleasing aquamarine green.

Development of Tastes and Odors

During the period when chlorine was being fed, the water of all pools exhibited the familiar odor and taste associated with the presence of that element or its compounds in water. It was more noticeable in some pools than in others but it was present everywhere. On the other hand, following the beginning of iodine feed no perceptible odor or taste was present in the water of any pool, a fact which was the subject of frequent comment not only by members of the study staff but by a large number of bathers using the pools. No complaints of eye irritation were received from bathers.

Summary and Conclusions

A study was made of the effectiveness of iodine as a disinfecting agent for swimming pool water. The study period extended from early July to mid-December, 1958. Eight pools were employed, seven in Gainesville, Fla., and one in Coral Gables, Fla. The pools varied in size from the Olympic-size pool of the University of Florida to small home-type pools at three motels, and in bathing loads from over 1,700 persons per day to as low as three persons per day. The study staff included, in addition to the three senior authors, two additional chemists, one bacteriologist, and two laboratory technicians. A total of 645 individual samples were analyzed chemically and bacteriologically, and a total of 6,588 tubes were inoculated. Over 1,600 miles were traveled by car in collecting samples during the study. Based upon the studies described in this report and the large amount of data collected, the following conclusions seem justified:

1. When compared upon the basis of halogen residuals in the range usually employed in swimming pools, iodine was fully effective in the disinfection of the water of the eight swimming pools treated. It was not only equal to chlorine but in many cases superior.

2. To maintain the desired iodine residual, particularly in pools with high bathing loads, required a much smaller applied dosage than was true of chlorine. Such iodine dosage was only slightly higher than that required for the disinfection of a home-type pool with a low bathing load.

3. To phrase the above conclusion in another way, iodine residuals appear to be much less dependent upon bather load than do chlorine residuals. This might be expected because iodine does not form substitution compounds with ammonia as does chlorine. One may conclude from this statement, therefore, that at the beginning of a bathing peak, a given iodine residual might be safer than a like "free" chlorine residual since there exists the strong possibility that the "free" chlorine residual might quickly be converted to a much less effective chloramine residual, whereas the iodine residual would not be affected by ammonia introduced by swimmers.

4. Because of the number of factors involved, it is not possible to give arbitrary figures for either chlorine demand or iodine demand which would fit all pool situations. However, it is easier to approximate the average iodine demand of swimming pools than the chlorine demand since it is much less dependent upon bathing load, the most important single factor involved. These studies appear to indicate that a daily dosage or one ppm of iodine would be sufficient under most conditions of use for home pools and perhaps double that figure for more heavily used public pools.

In terms of residuals, approximately 0.2 ppm of iodine should be sufficient to provide water of satisfactory quality. A residual of 0.1 ppm was almost as good.

5. No odors or tastes or irritations of the eyes of bathers were produced by the iodine residuals employed during the course of these studies.

6. Although most of the studies were conducted during the hot summer months with high temperatures predominating in seven of the pools, no visible growths of algae were noted during the testing period.

7. When iodine was uniformly distributed throughout the swimming pool either through the recirculation system or otherwise, no brown iodine color was observed, the over-all effect being the production of a pleasing aquamarine green color in the swimming pool water.

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APPENDIX A

Sampling

Individual samplers were constructed for each pool and left at the pool for use during the entire course of the investigation. A sampler consisted of a smooth nine-foot cypress pole with a four by four inch block nailed to the bottom. A one-liter narrow mouth glass stoppered bottle was placed on the block and stoutly wired in place with heavy aluminum wire. These samplers proved most satisfactory.

The method of sampling was as follows: The bottle was immersed in pool water, allowed to fill, inverted and allowed to drain while shaking vigorously. This procedure was repeated four times before a sample was collected. The bottle was then plunged almost to the bottom of the pool near the diving board at the deep end and the operator walked slowly to the corner of the pool, turned and proceeded toward the shallow end, meanwhile gradually raising the bottle toward the surface. Using this procedure approximately 18 seconds were required to fill the bottle which provided a representative composite sample both with respect to depth and area. The top was quickly removed from a wide mouth, 500 ml sterilized glass bottle containing sufficient sodium thiosulfate to remove the halogen residual. The bottle was quickly filled, almost but not quite to the top, from the sampling bottle, the top replaced and the sample immediately placed in the ice box. Ice boxes were available at all but one of the pools for refrigerating samples. Since the University of Florida pool adjoins the building in which the laboratory was located, all samples for bacteriological examination were carried to the laboratory by the pool attendant at the time of collection and dilutions immediately made by the laboratory staff.

At each pool the owner, operator, or a swimming pool attendant or life guard was selected and carefully trained in the technic of sample collection. These individuals routinely collected samples for bacteriological examination during the study period. Most of the time the field chemist on the project either assisted or supervised the collection of the first morning sample while on his rounds to collect the bacteriological samples of the previous day and leave fresh sterilized bottles for the current day. This procedure proved quite satisfactory and the results of the study indicate that very few samples were contaminated by handling during the course of the investigation.

Samples for chemical examination were collected twice daily, the first one in the morning at the time the field chemist made his rounds to collect the bacteriological samples of the previous day. A second visit was made to each pool in mid-afternoon by the field chemist and a second sample collected.

APPENDIX B

Laboratory Methods of Analysis—Bacteriological

Bacteriological analyses were made following exactly the methods outlined in "Standard

Methods for the Examination of Water, Sewage, and Industrial Wastes," Tenth Edition. Upon arrival at the laboratory all samples were entered in the log book, together with all pertinent data with respect to date and time of collection, pool number, and date of examination. Standard lactose broth (Difco dehydrated) was inoculated using three dilutions of the sample and three tubes per dilution. The dilutions used were three 100-ml portions, three 10-ml portions, and three one-ml portions. All tubes were incubated at 35° C. At the end of 24 hours' incubation, tubes were examined for gas production and the presence of gas was recorded as a positive presumptive. Using a sterile three-mm loop all positive tubes were transferred to Brilliant Green Bile Broth 2 per cent (Difco dehydrated) for confirmation of the coliform group. Production of gas in the B.G.B. tube was considered a positive test for the presence of the coliform group. The lactose broth tubes were incubated for an additional 24 hours and any tubes showing gas production were treated in a similar manner. In recording data positive presumptives failing to confirm in B.G.B. were ignored and only those samples confirming in B.G.B. were considered as positive. The "coliform index" was recorded as the "most probable numbers" per 100 ml of sample using Table 21c, page 386, in "Standard Methods for the Examination of Water, Sewage, and Industrial Wastes," Tenth Edition. Of a total of 6,588 lactose broth tubes inoculated during the course of the work from chlorine and iodine treated pools, about 15 per cent showed gas formation in 24 hours and an additional 5 per cent showed gas in 48 hours. Of the tubes showing gas in 24 hours, about 90 per cent confirmed in B.G.B., as might be expected, and of the tubes showing gas in lactose broth in 48 hours, about 70 per cent confirmed in B.G.B.

APPENDIX C

Laboratory Methods of Analysis—Chemical

Most determinations of residual chlorine during the first three weeks of this study were made using orthotolidine and kits available at the pool. Occasionally, however, an amperometric titrator was carried to some of the pools and determinations run at the pools. Similarly, during this period pH values were determined colorimetrically using pool kits.

When the feeding of iodine was begun, however, the one-liter morning and afternoon samples were placed in a slurry of cracked ice and water and carried to the laboratory for analysis. A number of tests, made both at pool site and on identical samples iced and carried to the laboratory, showed that iodine residuals did not decrease appreciably in samples so treated. Iodine residuals were determined amperometrically, and pH values were determined using a Beckman Model G pH meter. Three Wallace and Tiernan amperometric titrators were available and were used in rotation. When not in use electrodes were allowed to stand in a weak solution of iodine in order to increase the sensitivity of the instruments.

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